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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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WIND-TUNNEL INVESTIGATION OF EFFECTS OF FORWARD MOVEMENTS OF TRANSITION ON SECTION CHARACTERISTICS OF A LOW-DRAG AIRFOIL WITH A 0.24-CHORD SEALED PLAIN AILERON

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Langley Field, Va.

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SUMMARY

An investigation was conducted to determine the effects of forward movements of transition on the section characteristics of a 12-percent-thick low-drag airfoil section with a 0.24-chord sealed plain aileron. The section lift and aileron section hinge-moment and seal-pressure characteristics were determined at a Reynolds number of 14×10^6 for the condition with aerodynamically smooth surfaces, the condition with transition fixed at 0.30 chord, and the condition with transition fixed at the airfoil leading edge. Fixed transition at either 0.30 chord or at the airfoil leading edge resulted in a decreased aileron effectiveness, a decrease in the negative rate of change of aileron section hinge-moment coefficient with section angle of attack and with aileron deflection, and an increase in the absolute value of the aileron section hinge-moment parameter $\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$. Shifting the position of transition from approximately 0.50 chord to 0.30 chord generally caused larger changes in the aileron characteristics than those caused by shifting transition from 0.30 chord to the airfoil leading edge. Leading-edge roughness decreased the maximum section lift coefficient by about 0.3; whereas roughness at 0.30 chord generally caused no significant change in the maximum section lift coefficient.

INTRODUCTION

Aerodynamic characteristics of ailerons on low-drag wing sections may be satisfactory when the wing surfaces are aerodynamically smooth, but forward movements of the position of transition from laminar to turbulent flow caused by manufacturing irregularities or surface deterioration in service may result in undesirable changes in the aileron characteristics. The results of previous investigations, for example, those reported in references 1 and 2, illustrate the changes in the two-dimensional characteristics of control surfaces, such as the decreased effectiveness, that usually result from forward movements of transition. Such investigations, however, have been limited to a small range of control-surface deflection for various chordwise positions of transition, and the Reynolds number has generally been limited to about 9.0×10^6. An investigation was made in the Langley two-dimensional low-turbulence pressure tunnel to determine the effects of transition shifting from approximately 0.50 chord to 0.30 chord and to the airfoil leading edge on the characteristics of a 24-percent-chord sealed plain aileron on a 12-percent-thick low-drag airfoil for aileron deflections ranging from -20° to 20° and a Reynolds number of 14×10^6.

COEFFICIENTS AND SYMBOLS

α_o section angle of attack, degrees

$\Delta\alpha_o$ increment of section angle of attack, degrees

c airfoil chord

c_l section lift coefficient

q_o free-stream dynamic pressure

c_a aileron chord behind hinge axis

δ_a aileron deflection, degrees

$\Delta\delta_a$ increment of aileron deflection, degrees

h_a aileron section hinge moment per unit span; positive when aileron tends to deflect downward

c_{h_a} aileron section hinge-moment coefficient based on aileron chord $\left(\frac{h_a}{q_o {c_a}^2}\right)$

$\left(c_{h_a}\right)_{\delta_T}$ total $\frac{dc_{h_a}}{d\delta_a}$ in steady roll

$\left(\Delta c_{h_a}\right)_\alpha$ increment of aileron section hinge-moment coefficient due to change in section angle of attack at constant aileron deflection

$\left(\Delta c_{h_a}\right)_\delta$ increment of aileron section hinge-moment coefficient due to aileron deflection at a constant section angle of attack

c_H — aileron section hinge-moment coefficient based on airfoil chord $\left(\frac{h_a}{q_o c^2}\right)$

Δc_{H_T} — increment of total aileron section hinge-moment coefficient in steady roll

$\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ — aileron section hinge-moment parameter

$\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm20^\circ}$ — aileron section effectiveness parameter for range of aileron deflection indicated by subscript (ratio of increment of section angle of attack to increment of aileron deflection required to maintain constant section lift coefficient)

$\Delta p/q_o$ — seal-pressure-difference coefficient; positive when pressure below aileron seal is greater than pressure above seal

$\alpha_\delta = \left(\frac{\partial\alpha_o}{\partial\delta_a}\right)_{c_l}$ — aileron section effectiveness parameter

R — Reynolds number

$$c_{l_\alpha} = \left(\frac{\partial c_l}{\partial\alpha_o}\right)_{\delta_a}$$

$$c_{l_\delta} = \left(\frac{\partial c_l}{\partial\delta_a}\right)_{\alpha_o}$$

$$\left(c_{h_a}\right)_\alpha = \left(\frac{\partial c_{h_a}}{\partial\alpha_o}\right)_{\delta_a}$$

$$\left(c_{h_a}\right)_\delta = \left(\frac{\partial c_{h_a}}{\partial\delta_a}\right)_{\alpha_o}$$

$$P_\alpha = \left(\frac{\partial\frac{\Delta p}{q_o}}{\partial\alpha_o}\right)_{\delta_a}$$

$$P_\delta = \left(\frac{\partial\frac{\Delta p}{q_o}}{\partial\delta_a}\right)_{\alpha_o}$$

The subscripts to the partial derivatives denote the variables held constant when the partial derivatives were obtained. The derivatives were measured at zero angle of attack and zero aileron deflection.

MODEL AND TESTS

The model tested in this investigation had a chord of 3 feet and completely spanned the 3-foot-wide tunnel test section. The low-drag airfoil section had a maximum thickness of 0.12c at 0.45c, a design lift coefficient of 0.15, and a mean line designed for a uniform load over the forward 0.9 chord. Ordinates for the plain airfoil section are given in table I. The plain aileron (fig. 1) formed by the rear part of the plain airfoil section had a chord of 0.24c and was sealed along the entire span and at both ends with thin rubber seals (fig. 1). The main part of the model forward of the aileron was constructed of laminated wood, and the aileron was constructed of dural. The aileron was supported at both ends by beams that contained electrical-resistance-type strain gages for measuring hinge moments. The model was tested with the surfaces aerodynamically smooth and with fixed transition at 0.30 chord on both surfaces, and with transition fixed at the leading edge as shown in figure 2. The transition strips were comprised of 0.011-inch carborundum grains.

The section characteristics measured in the Langley two-dimensional low-turbulence pressure tunnel consisted of the airfoil section lift, aileron section hinge-moment, and seal-pressure characteristics at a Reynolds number of 14×10^6 for each of the three surface configurations tested for aileron deflections ranging from -20° to 20°. The lift characteristics were determined by the method discussed in reference 3. The resultant pressure acting on the aileron seal was determined from static pressure measurements above and below the aileron seal. A discussion of the test methods and of the methods used in correcting the test data to free-air conditions is given in reference 3. The maximum free-stream Mach number attained during the tests was approximately 0.17.

RESULTS AND DISCUSSION

The section characteristics for the condition with aerodynamically smooth surfaces, the condition with fixed transition at 0.30c, and the condition with transition fixed at the airfoil leading edge are presented in figures 3, 4, and 5, respectively.

Aileron Effectiveness

Values of the aileron effectiveness parameters c_{l_δ}, α_δ, and $\Delta\alpha_o/\Delta\delta_a$, obtained from the data presented in figures 3 to 5, are presented in table II. Forward movement of the position of transition from its normal position at approximately 0.50c to the airfoil leading edge decreased the value of c_{l_δ} by approximately 2 percent. The decrease in the absolute value of α_δ resulting from shifting transition from approximately 0.50c to 0.30c was the same as that obtained by shifting transition from about 0.50c to the airfoil leading edge. The absolute value of α_δ for the smooth condition (0.524) was approximately 12 percent less than the theoretical value obtained from reference 4 and about 4 percent greater than that reported in reference 4 for the NACA 0009 airfoil.

The variation of $\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm 10^\circ}$ and $\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm 20^\circ}$ with section lift coefficient is shown in figure 6. At section lift coefficients below about 0.5, the absolute value of $\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm 10^\circ}$ was reduced approximately 5 percent because of the forward shift of transition from its normal position to either 0.30c or the airfoil leading edge, whereas the reduction in the absolute value of $\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm 20^\circ}$ was approximately 15 percent. At section lift coefficients higher than about 0.5, fixing transition at a forward chordwise position caused considerably less change in the values of $\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm 10^\circ}$ and $\left(\frac{\Delta\alpha_o}{\Delta\delta_a}\right)_{\delta_a=\pm 20^\circ}$ than the change obtained at lower lift coefficients.

In general, moving the position of transition from approximately 0.50c to 0.30c resulted in much greater changes in the aileron effectiveness parameters than those caused by shifting transition from 0.30c to the airfoil leading edge.

Hinge Moments

The section hinge-moment characteristics for the three surface configurations tested are presented in figures 3 to 5. Values of the rate of change of aileron section hinge-moment coefficient c_{h_a} with section angle of attack α_o and with aileron deflection δ_a are presented in table II. The values of $\left(c_{h_a}\right)_\alpha$ and $\left(c_{h_a}\right)_\delta$ for the condition with aerodynamically smooth surfaces were -0.0038 and -0.0081, respectively. The value of $\left(c_{h_a}\right)_\alpha$ for the smooth condition was measured between section angles of attack of 3° and 8° because of the slight irregularity in the curve for an aileron deflection of 0° as shown in figure 3(b). A forward movement of transition decreased the absolute values of both $\left(c_{h_a}\right)_\alpha$ and $\left(c_{h_a}\right)_\delta$. The data presented in figures 3 to 5 indicate that the hinge-moment curves tend to become more linear as transition moves toward the airfoil leading edge.

The variation of the section hinge-moment coefficient with aileron deflection, at the design section lift coefficient of 0.15, is presented in figure 7. These curves indicate that a movement of transition from its normal position at approximately 0.50c to 0.30c had considerably more effect on the aileron hinge moments than a farther forward shift in the position of transition from 0.30c to the airfoil leading edge.

The aileron section hinge-moment and seal-pressure data may be used to predict the hinge-moment characteristics of ailerons similar to that tested in this investigation and having any amount of internal balance. A method for estimating the hinge-moment characteristics of balanced ailerons from data for plain ailerons is discussed in reference 5.

Values of the hinge-moment parameter $\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ for a section lift coefficient of 0.15 were determined from the basic section data by use of the following equation obtained from reference 2:

$$\Delta c_{H_T} = \left(\frac{c_a}{c}\right)^2 \left\{\left(\Delta c_{h_a}\right)_\delta \left[1 - \frac{n}{\Delta\alpha_o/\Delta\delta_a} \frac{\left(\Delta c_{h_a}\right)_\alpha}{\left(\Delta c_{h_a}\right)_\delta}\right]\right\}$$

As discussed in reference 2, the foregoing equation is essentially the equation:

$$\left(c_{h_a}\right)_{\delta_T} = \left(c_{h_a}\right)_\delta \left[1 - n\frac{\left(c_{h_a}\right)_\alpha}{\left(c_{h_a}\right)_\delta}\right]$$

modified in such a way as to be applicable to nonlinear curves. This equation is a modification of a similar equation based on the assumption that a section of the aileron acts at a constant lift during a steady roll regardless of the rate of roll. The modification was made to correct for the fact that the constant lift assumption overstresses the importance of the factor $\left(c_{h_a}\right)_\alpha$. The parameter $\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ provides a comparison between aileron configurations and takes into account the aileron effectiveness, hinge moments, and the possible mechanical advantage between the controls and ailerons. Although the parameter is inadequate for calculating the hinge moments of finite-span ailerons, it is considered satisfactory for comparing two-dimensional characteristics.

In computing the values of Δc_{H_T} for the two-dimensional case, the value of n, which is the change in section angle of attack at midspan of aileron per unit aileron deflection, was assumed to be $\frac{1}{5}$, which is a typical value also used in reference 2. The variation of the hinge-moment parameter $-\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ with equivalent change in section angle of attack required to maintain a constant section lift coefficient of 0.15 is shown in figure 8. The lower the absolute value of $\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ at a given value of $\Delta\alpha_o$, the lower the control force should be for a given helix angle of the wing tip. In general, the increase in the absolute value of $\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$, caused by moving the chordwise position of transition forward, became greater with increase in the value of $\Delta\alpha_o$ for all locations of transition. Shifting transition from approximately the midchord of the airfoil to 0.30c generally caused a greater change in the value of $\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ than shifting transition from 0.30c to the airfoil leading edge.

Lift

The slope of the lift curve c_{l_α} was reduced by only 3 percent by the application of roughness to the airfoil leading edge as indicated by the results presented in table II. The values of c_{l_α} for the condition with aerodynamically smooth surfaces and the condition with roughness at 0.30c were 0.104 and 0.103, respectively, or very nearly the same.

The variation of maximum section lift coefficient with aileron deflection is shown in figure 9. Throughout most of the range of aileron deflection tested, the application of roughness strips at 0.30c on the smooth airfoil caused no significant change in the maximum section lift coefficient. Leading-edge roughness, however, decreased the maximum section lift coefficient by approximately 0.3 throughout most of the range of aileron deflection tested.

CONCLUSIONS

The results of an investigation made to determine the effects of forward movements of transition on the section characteristics of a 12-percent-thick low-drag airfoil with a 0.24-chord sealed plain aileron indicate the following conclusions:

1. Fixed transition at either 0.30 chord on both airfoil surfaces or at the airfoil leading edge caused:

(a) The aileron effectiveness to decrease

(b) The negative rate of change of aileron section hinge-moment coefficient with section angle of attack and with aileron deflection to decrease

(c) The absolute value of the aileron section hinge-moment parameter $\dfrac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ to increase

(d) The rate of change of section lift coefficient with section angle of attack to decrease by not more than 3 percent

2. Shifting the position of transition from approximately 0.50 chord to 0.30 chord generally caused larger changes in the aileron characteristics than those caused by shifting transition from 0.30 chord to the airfoil leading edge.

3. Leading-edge roughness decreased the maximum section lift coefficient by about 0.3; whereas roughness at 0.30 chord had no significant effect on the maximum section lift coefficient throughout most of the range of aileron deflection tested.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 5, 1947

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5. Fischel, Jack: Hinge Moments of Sealed-Internal-Balance Arrangements for Control Surfaces. II - Experimental Investigation of Fabric Seals in the Presence of a Thin-Plate Overhang. NACA ARR No. L5F30a, 1945.

TABLE I

ORDINATES FOR PLAIN AIRFOIL SECTION

[Stations and ordinates given in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.50	.975	.50	-.808
.75	1.192	.75	-1.006
1.25	1.539	1.25	-1.283
2.50	2.161	2.50	-1.792
5.00	3.022	5.00	-2.489
7.50	3.678	7.50	-2.961
10.00	4.211	10.00	-3.336
15.00	5.022	15.00	-3.922
20.00	5.625	20.00	-4.344
25.00	6.108	25.00	-4.631
30.00	6.464	30.00	-4.844
35.00	6.711	35.00	-4.983
40.00	6.856	40.00	-5.064
45.00	6.917	45.00	-5.078
50.00	6.883	50.00	-5.019
55.00	6.739	55.00	-4.875
60.00	6.464	60.00	-4.633
65.00	6.039	65.00	-4.272
70.00	5.492	70.00	-3.786
75.00	4.814	75.00	-3.203
80.00	3.969	80.00	-2.542
85.00	3.028	85.00	-1.847
90.00	2.028	90.00	-1.153
95.00	.989	95.00	-.539
100.00	.019	100.00	-.019
L.E. radius: 0.800 L.E. radius center located 0.056 above chord line			

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TABLE II

SECTION PARAMETERS MEASURED AT $\alpha_0 = 0^\circ$, $\delta_a = 0^\circ$, AND $R = 14 \times 10^6$

EXCEPT FOR $\left(\frac{\Delta\alpha_0}{\Delta\delta_a}\right)_{\delta_a=\pm10^\circ}$ AND $\left(\frac{\Delta\alpha_0}{\Delta\delta_a}\right)_{\delta_a=\pm20^\circ}$ MEASURED AT $c_l = 0.15$

Surface	c_{l_α}	c_{l_δ}	α_δ	$\left(\frac{\Delta\alpha_0}{\Delta\delta_a}\right)_{\delta_a=\pm10^\circ}$	$\left(\frac{\Delta\alpha_0}{\Delta\delta_a}\right)_{\delta_a=\pm20^\circ}$	$\left(c_{h_a}\right)_\alpha$	$\left(c_{h_a}\right)_\delta$	P_α	P_δ
Smooth	0.104	0.052	-0.524	-0.535	-0.525	-0.0038	-0.0081	0.035	0.100
Roughness at 0.30c	.103	.052	-.492	-.502	-.446	-.0036	-.0079	.038	.098
Roughness at leading edge	.101	.051	-.492	-.502	-.438	-.0030	-.0078	.036	.097

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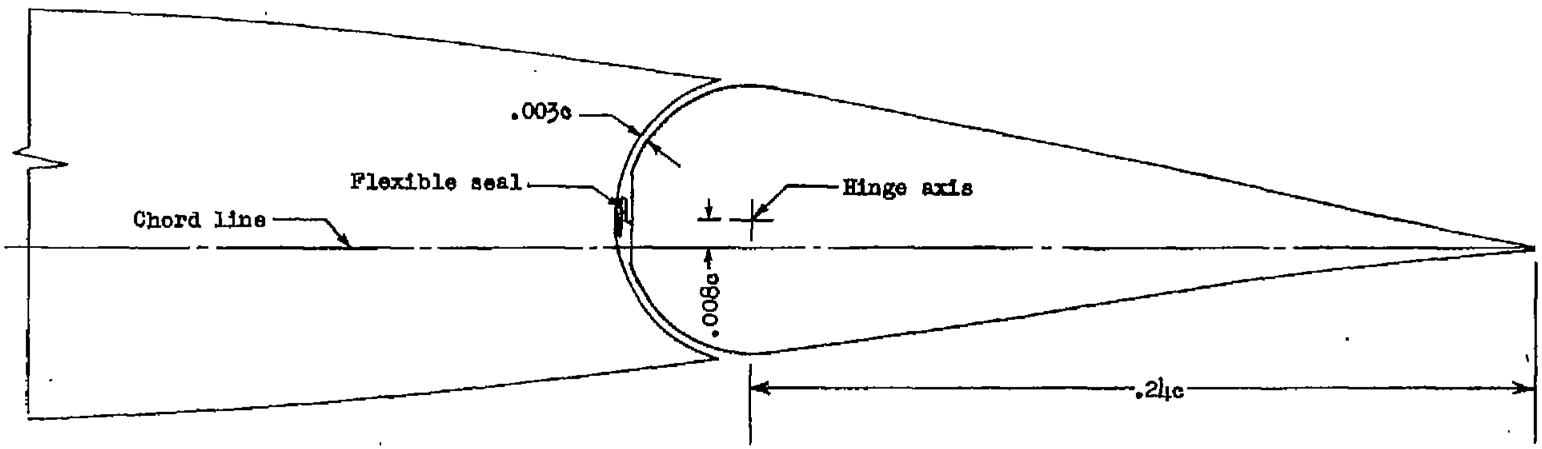

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Figure 1.- Profile of the 0.24c sealed aileron.

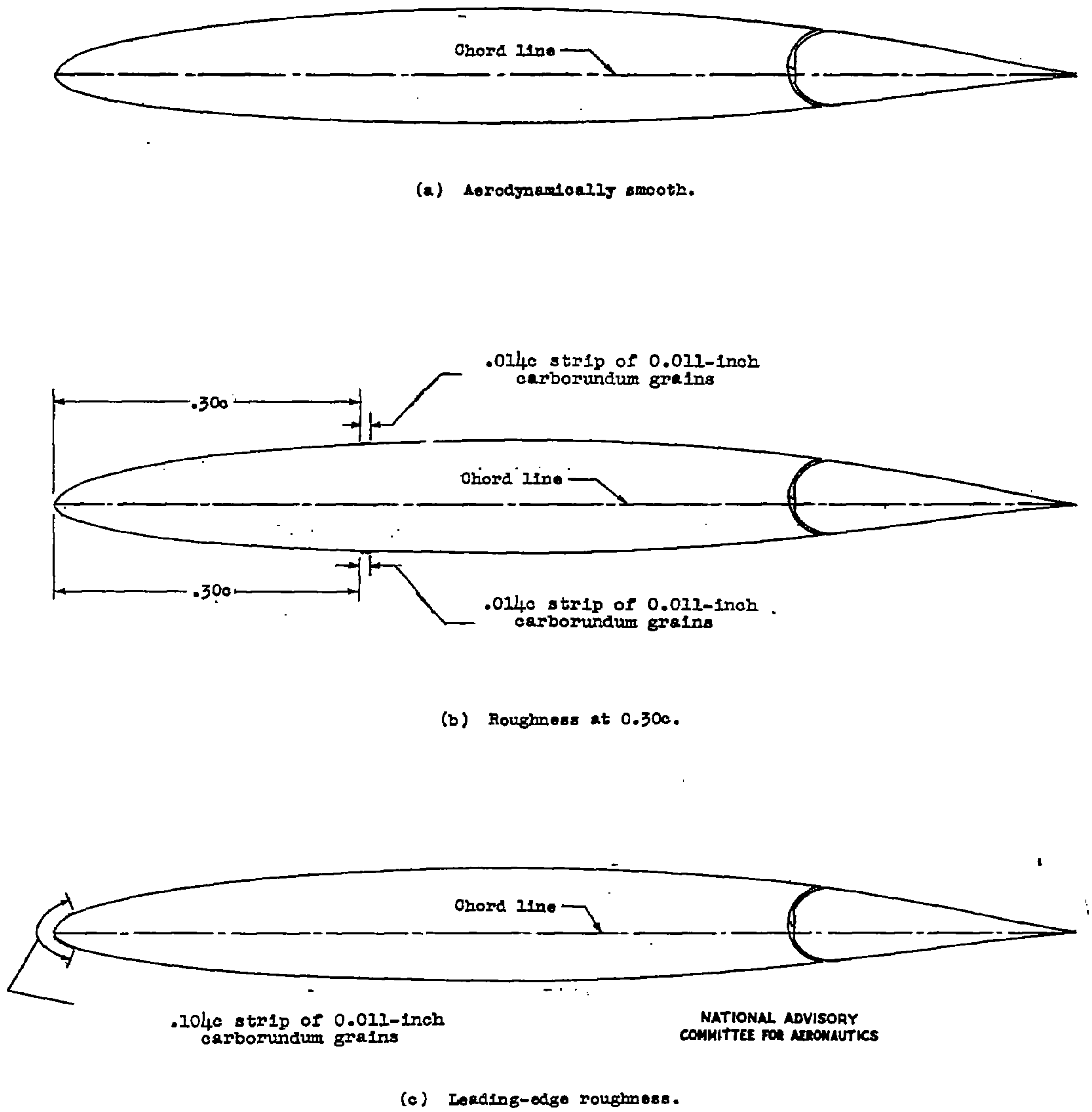
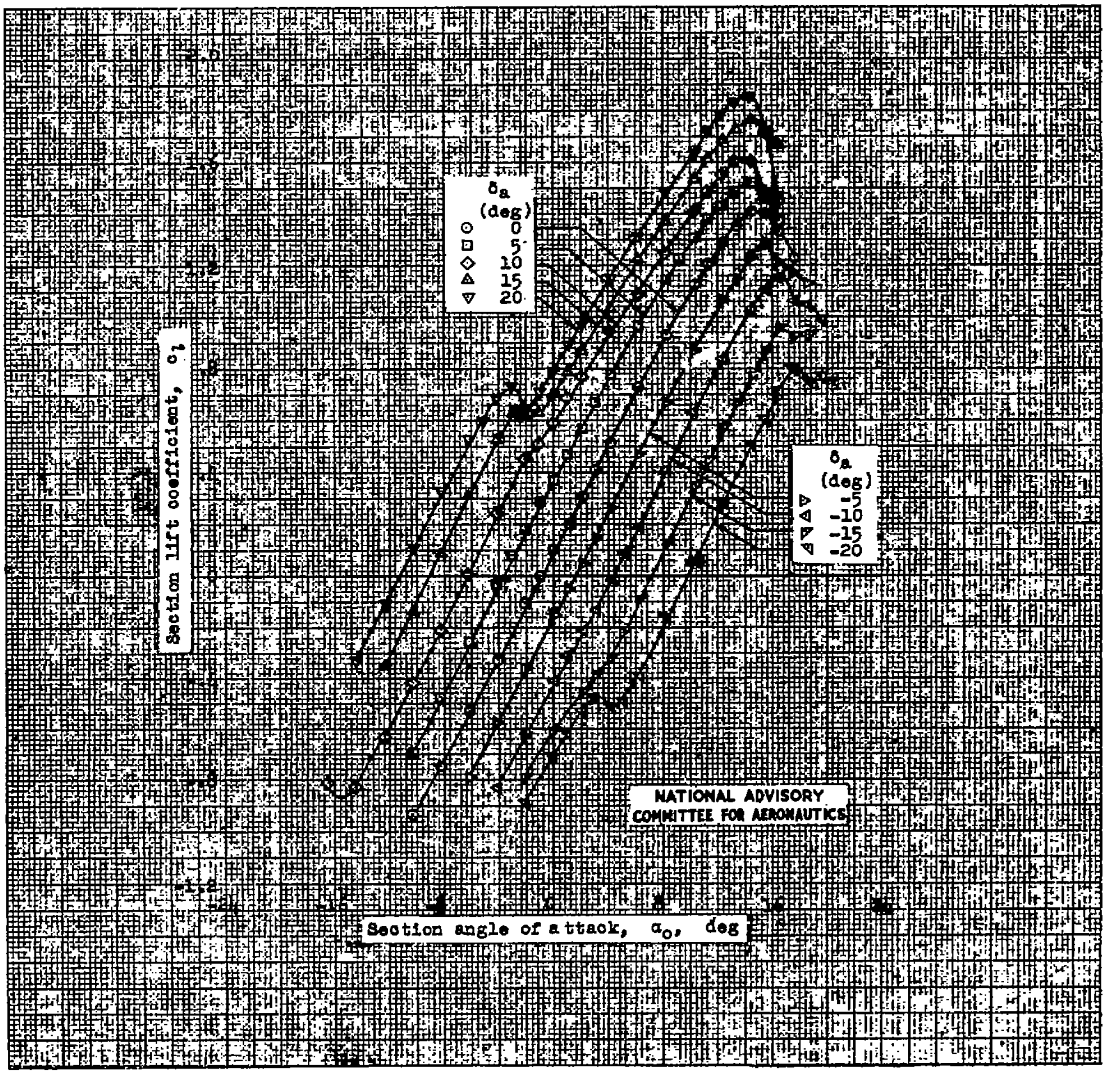
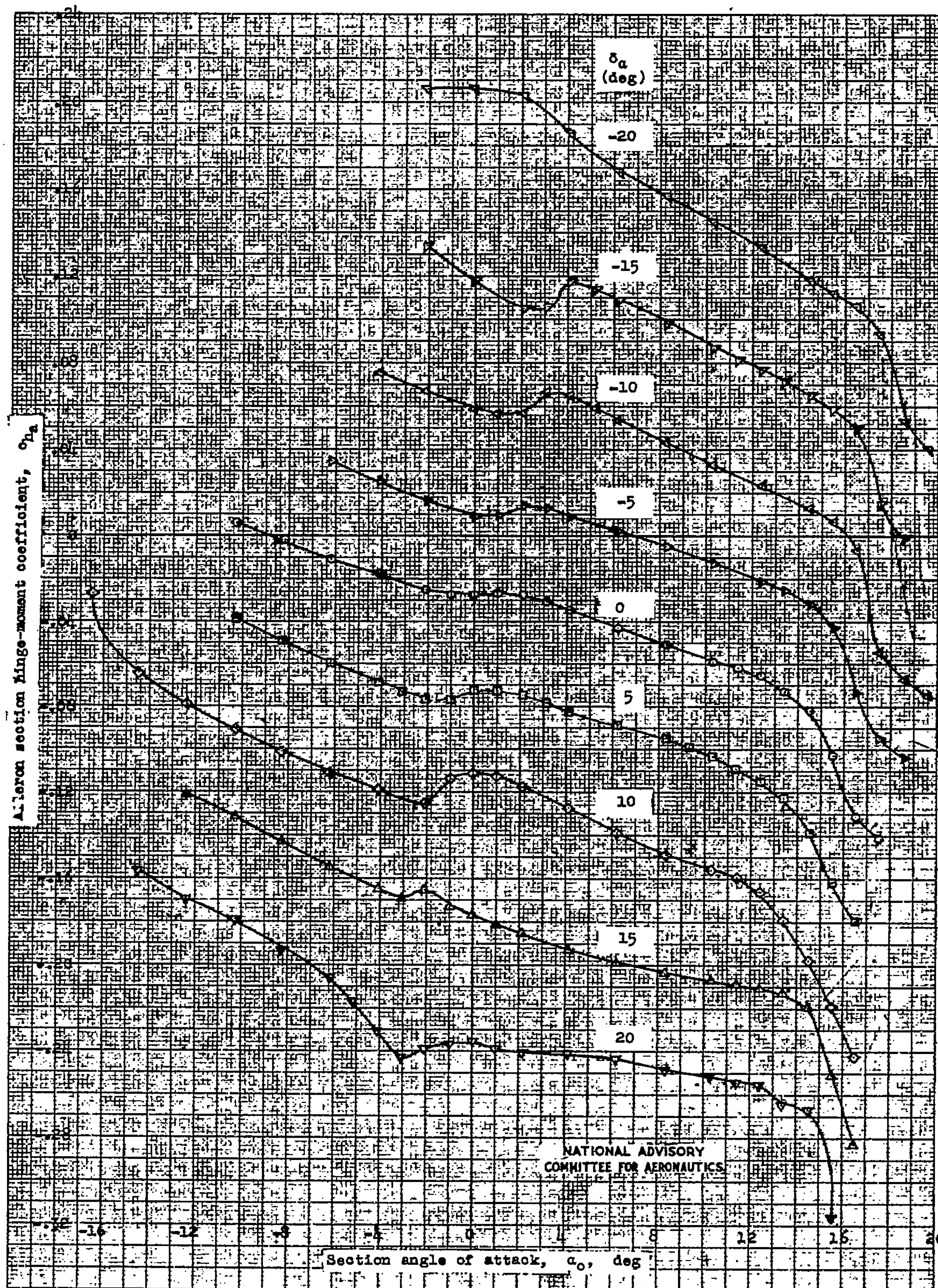


Figure 2.- Surface configurations of the low-drag airfoil section equipped with a 0.24c sealed aileron.



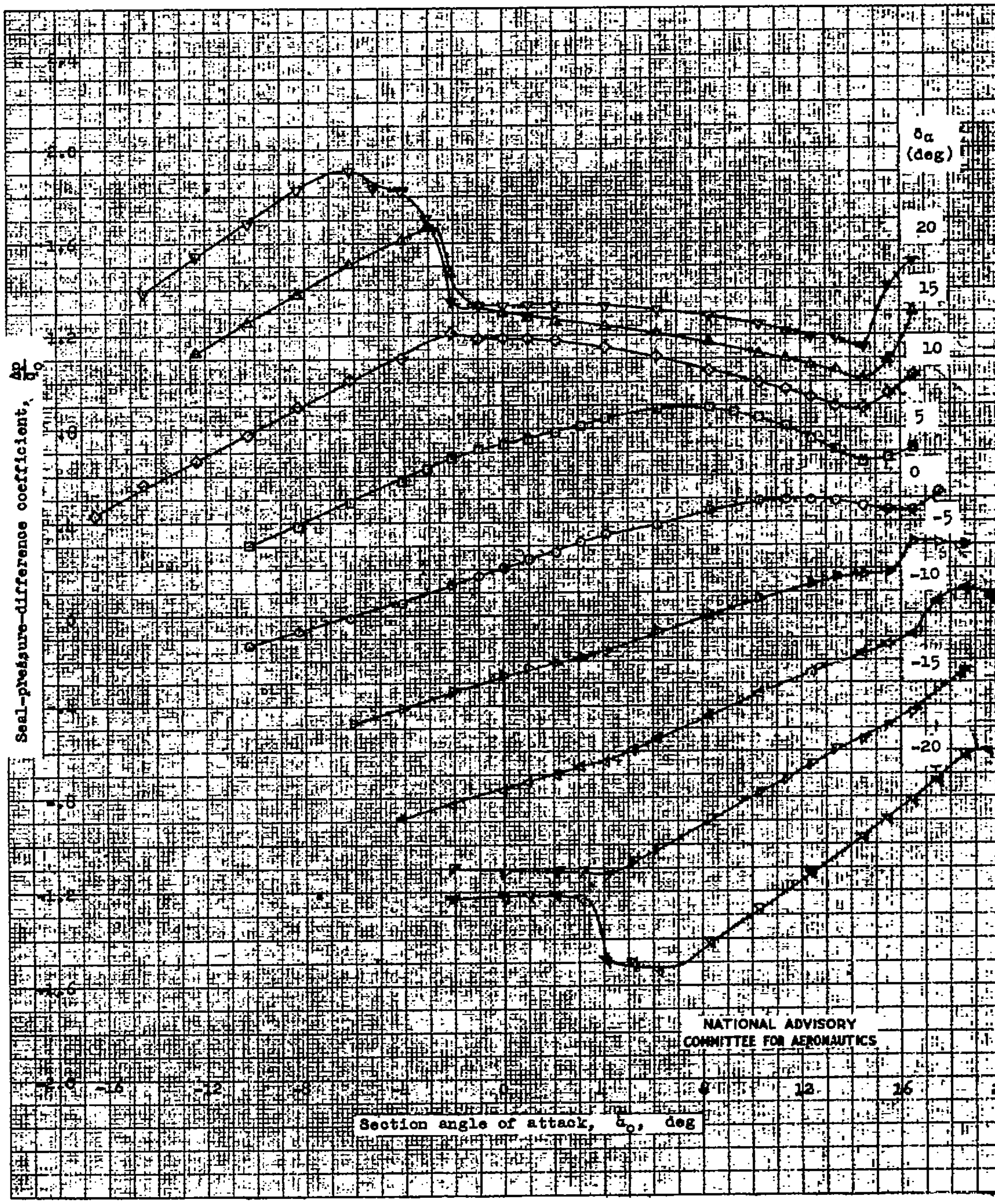
(a) Lift characteristics.

Figure 3.- Section characteristics of the low-drag airfoil section with a 0.24c sealed aileron and with aerodynamically smooth surfaces. $R = 14 \times 10^6$.



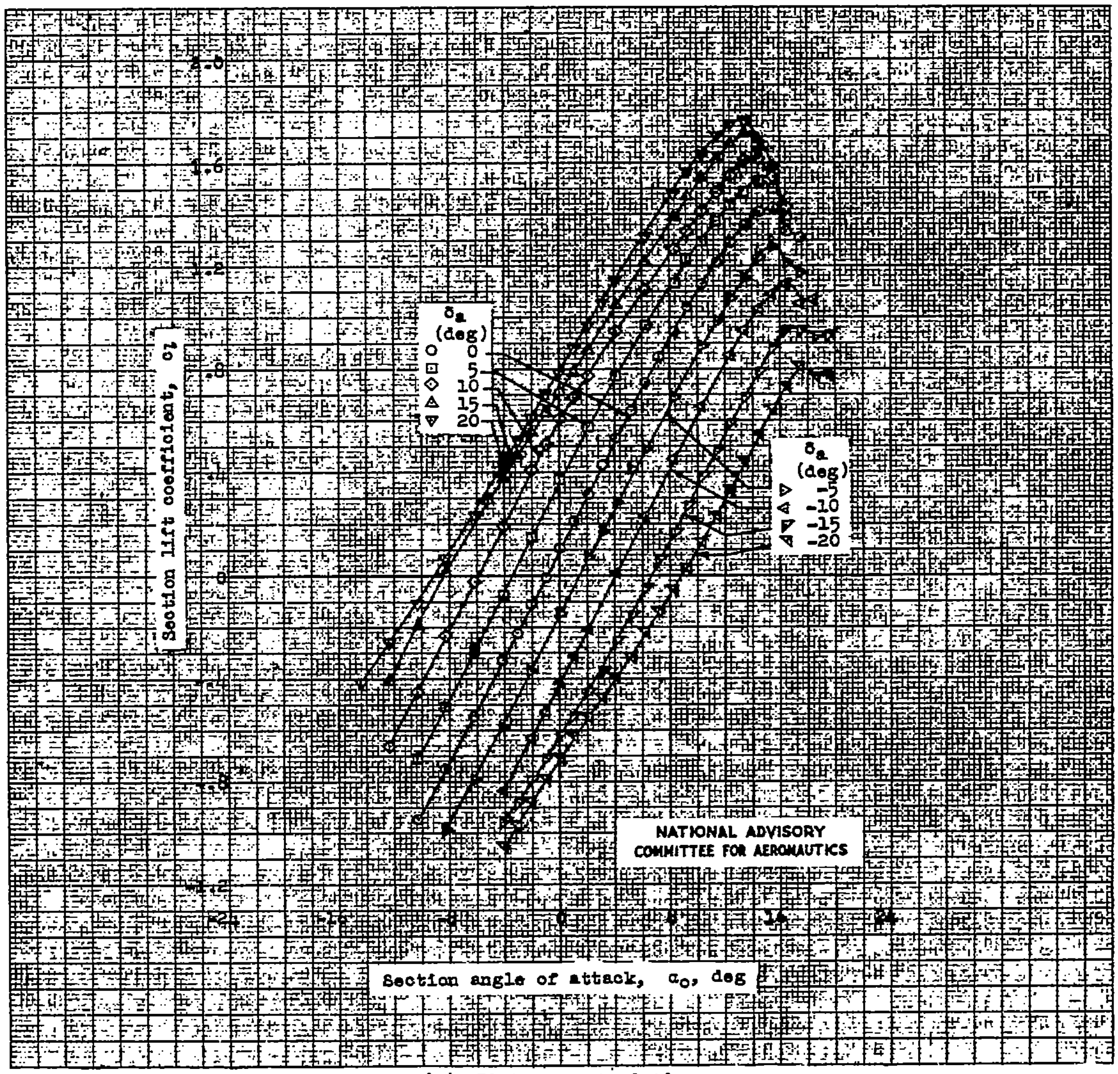
(b) Hinge-moment characteristics.

Figure 3.- Continued.



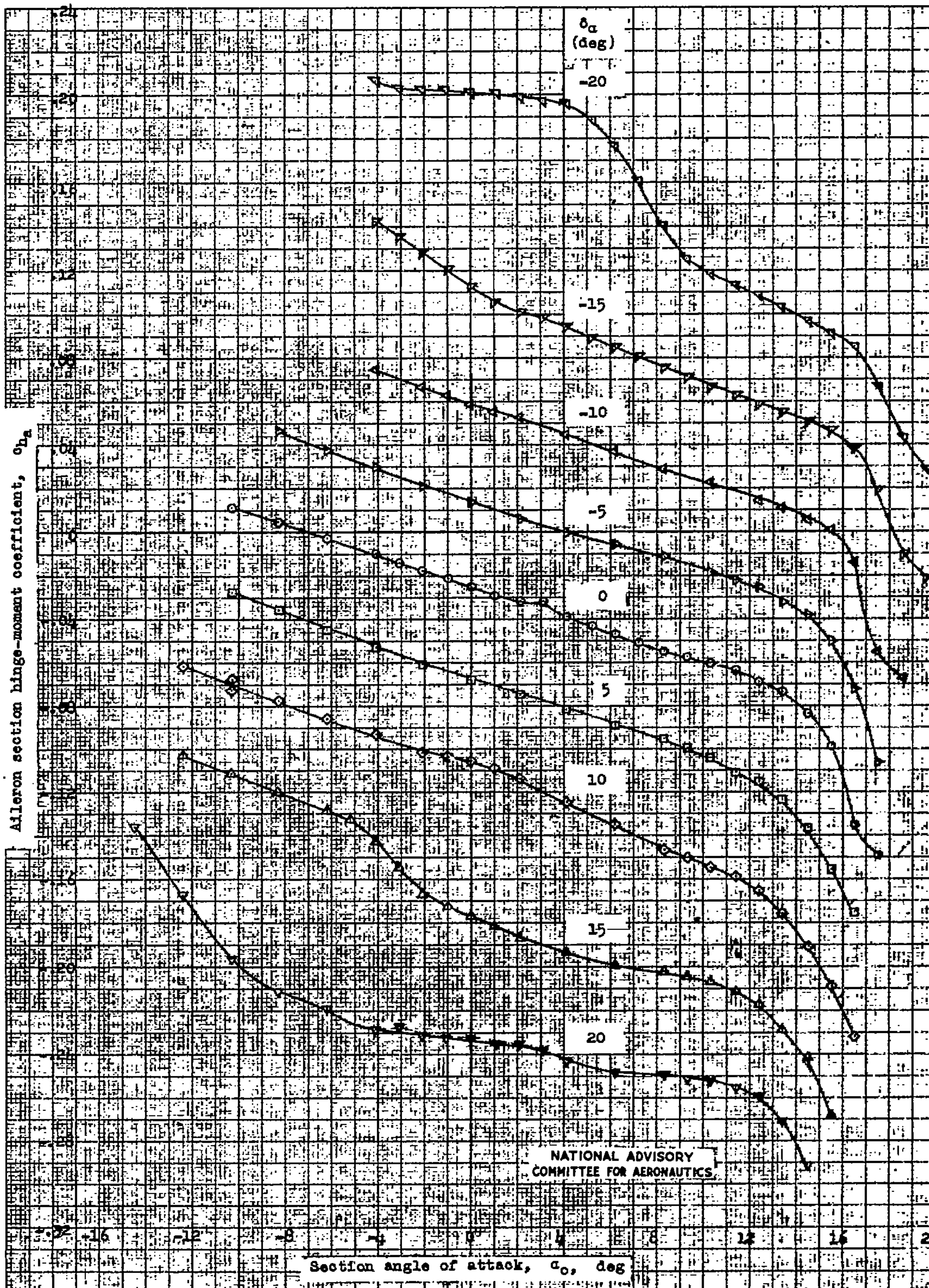
(c) Seal-pressure characteristics.

Figure 3.- Concluded.



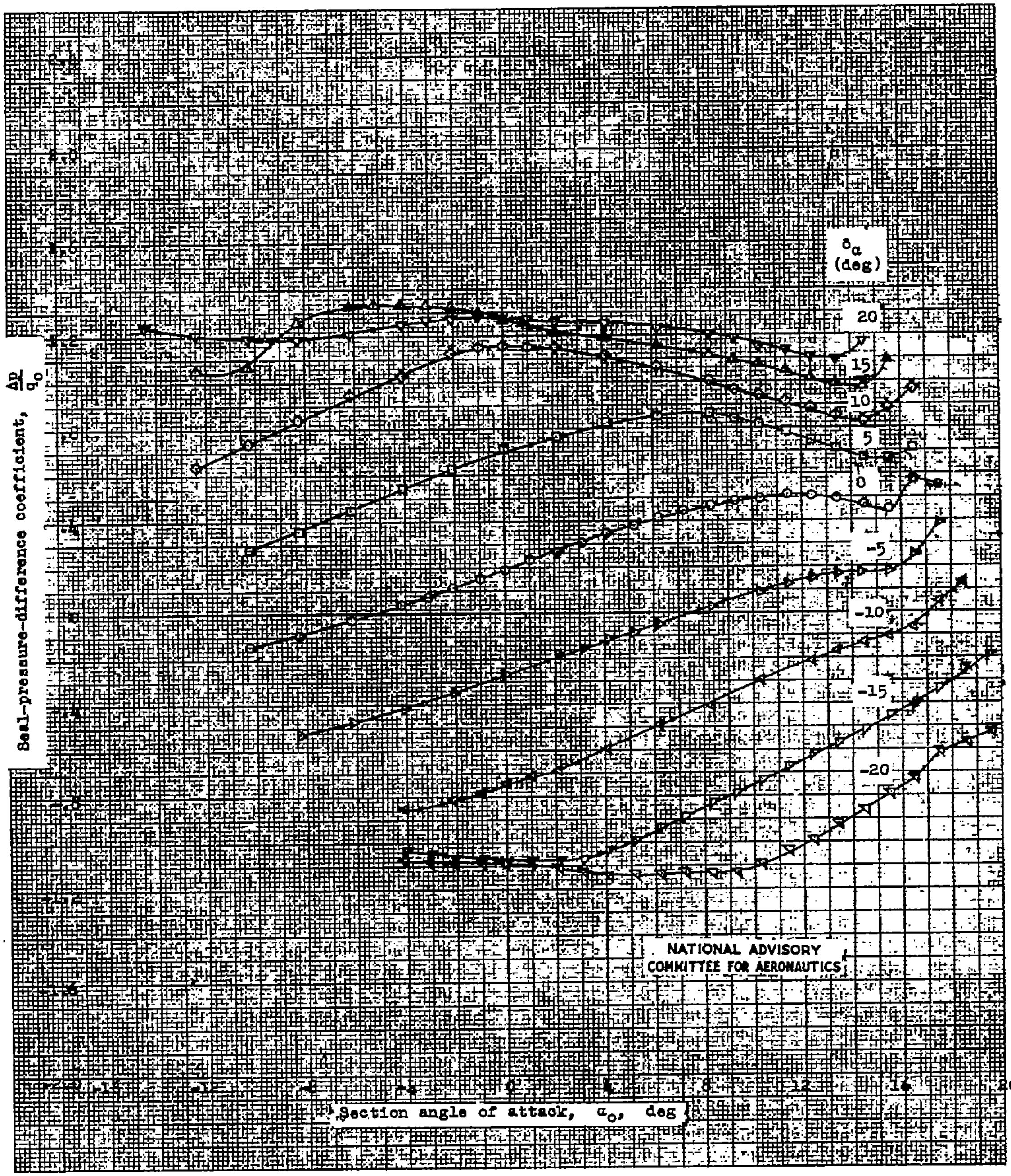
(a) Lift characteristics.

Figure 4.- Section characteristics of the low-drag airfoil section with a 0.24c sealed aileron and with 0.014c spanwise strips of roughness at 0.30c on upper and lower surfaces. $R = 14 \times 10^6$.



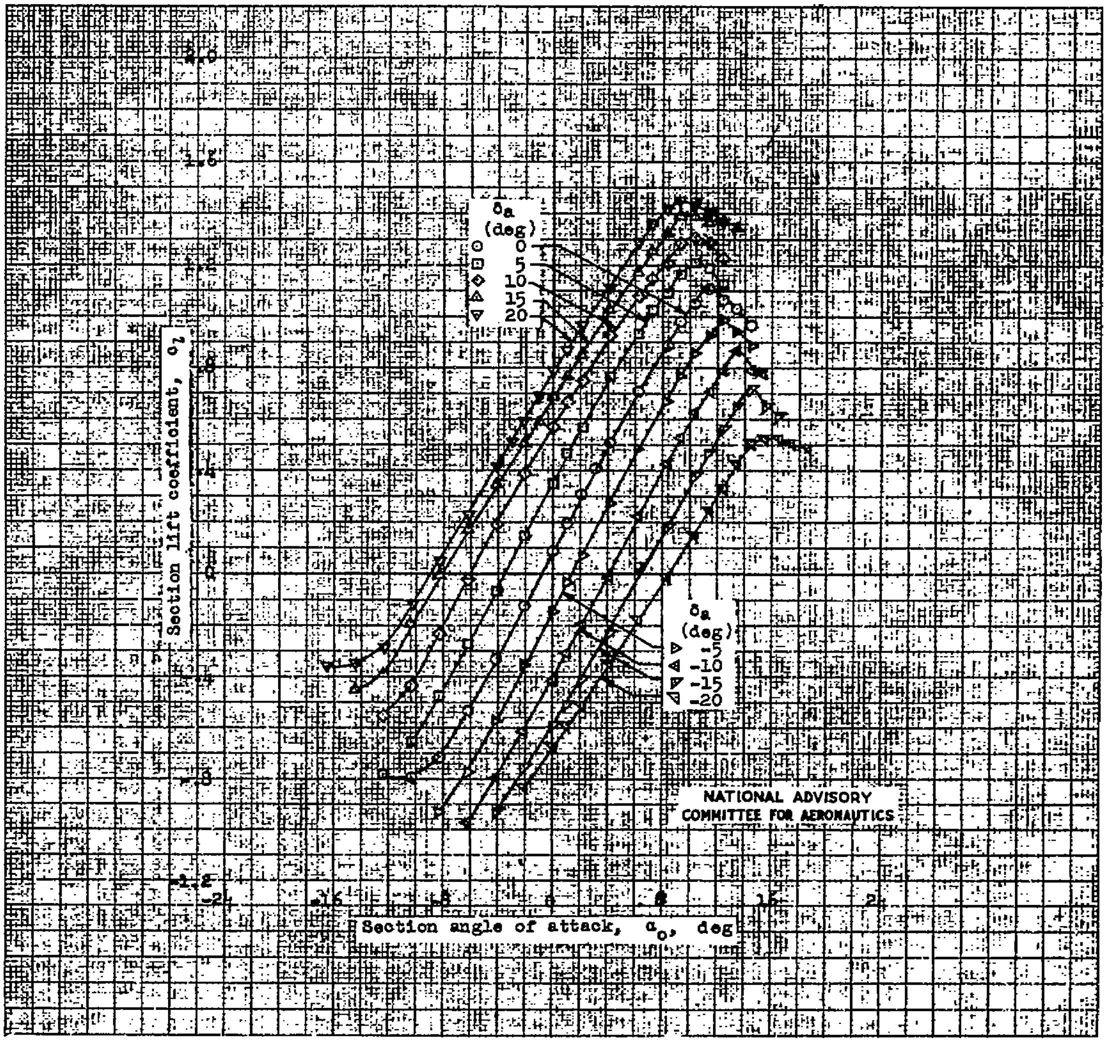
(b) Hinge-moment characteristics.

Figure 4.- Continued.



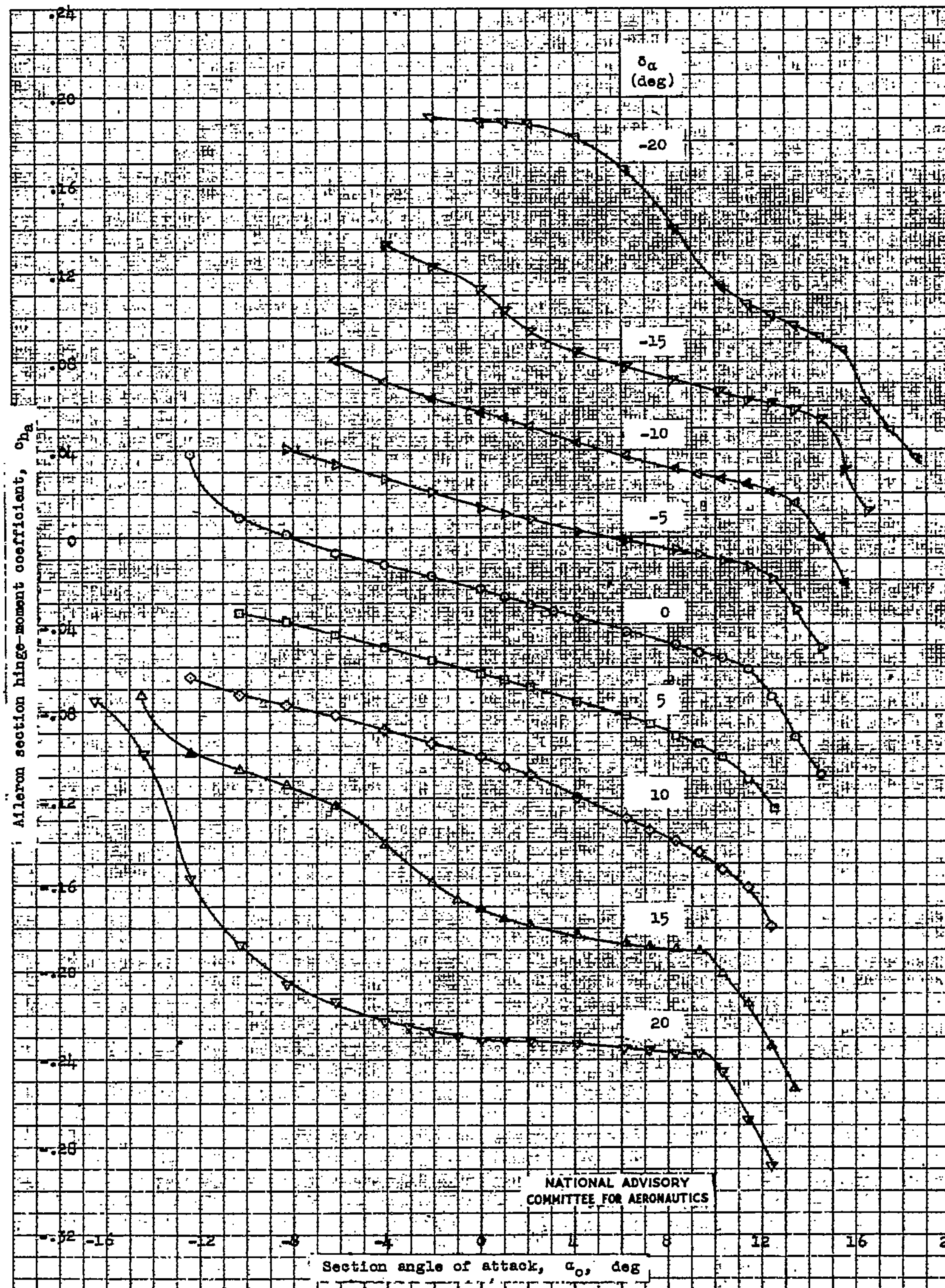
(c) Seal-pressure characteristics.

Figure 4.- Concluded.



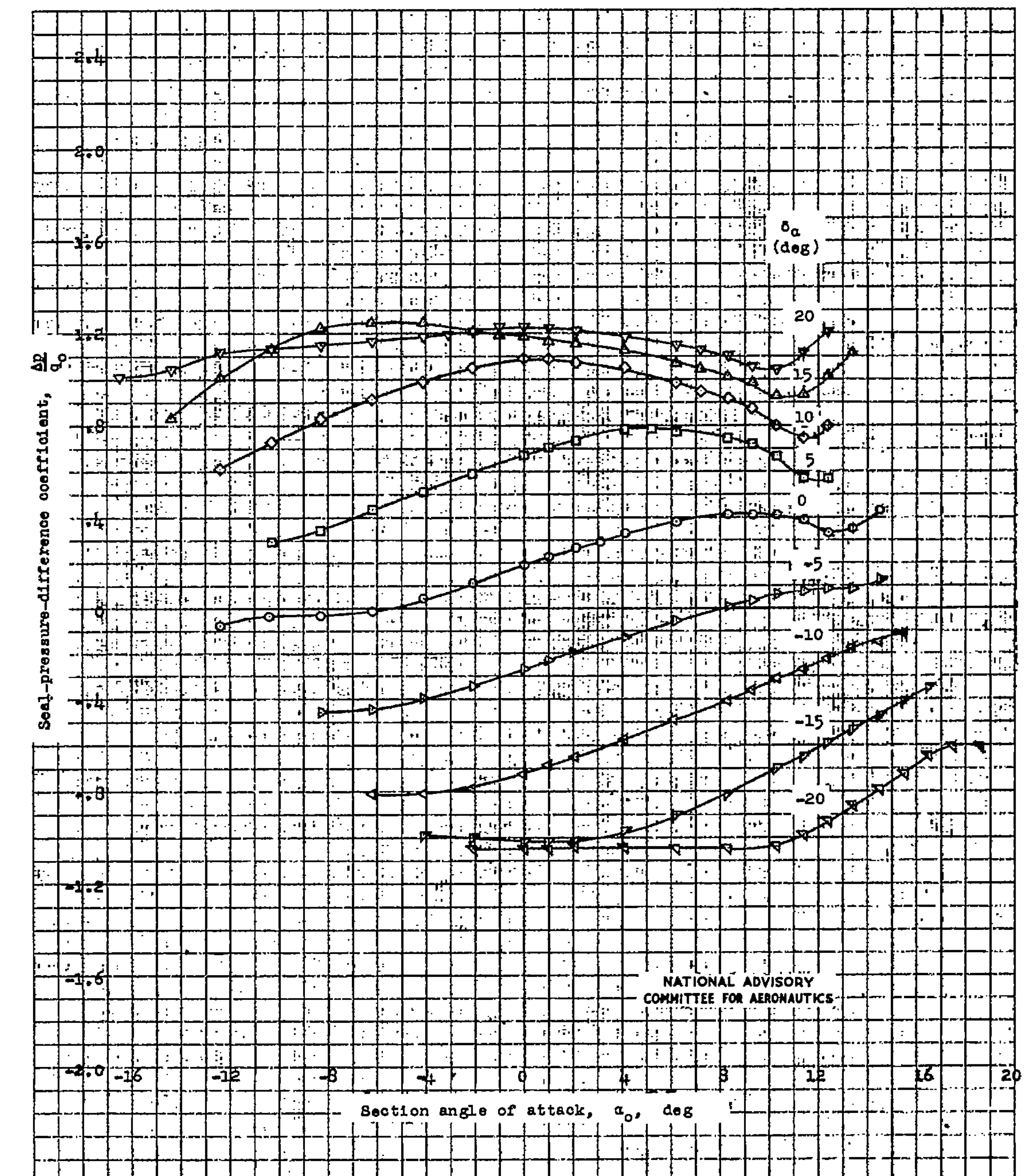
(a) Lift characteristics.

Figure 5.- Section characteristics of the low-drag airfoil section with a 0.24c sealed aileron and with a 0.104c spanwise strip of roughness on the airfoil leading edge. $R = 14 \times 10^6$.



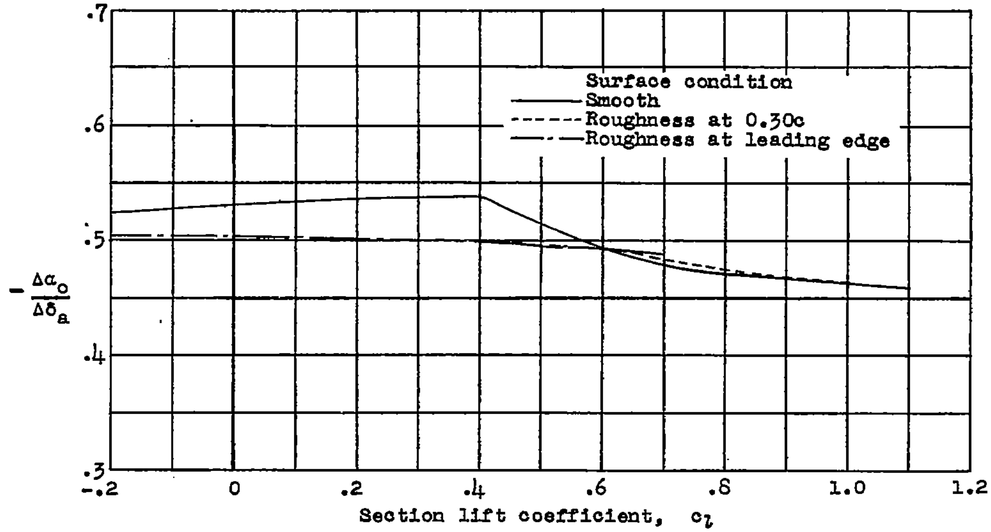
(b) Hinge-moment characteristics.

Figure 5.- Continued.

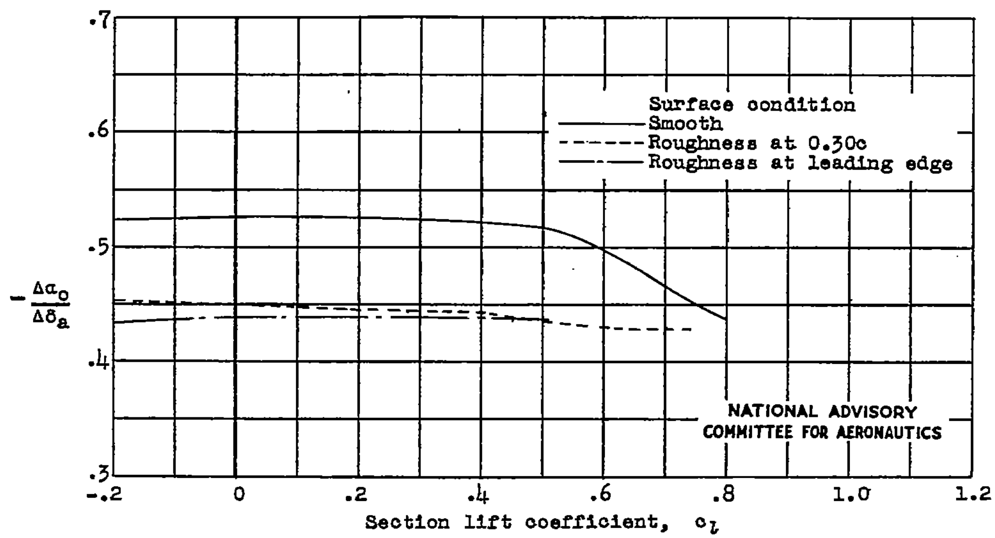


(c) Seal-pressure characteristics.

Figure 5.- Concluded.



(a) $\delta_a = \pm 10^\circ$.



(b) $\delta_a = \pm 20^\circ$.

Figure 6.- Variation of aileron effectiveness parameter $\Delta\alpha_o/\Delta\delta_a$ with section lift coefficient for the 0.24c sealed aileron on the low-drag airfoil section. $R = 14 \times 10^6$.

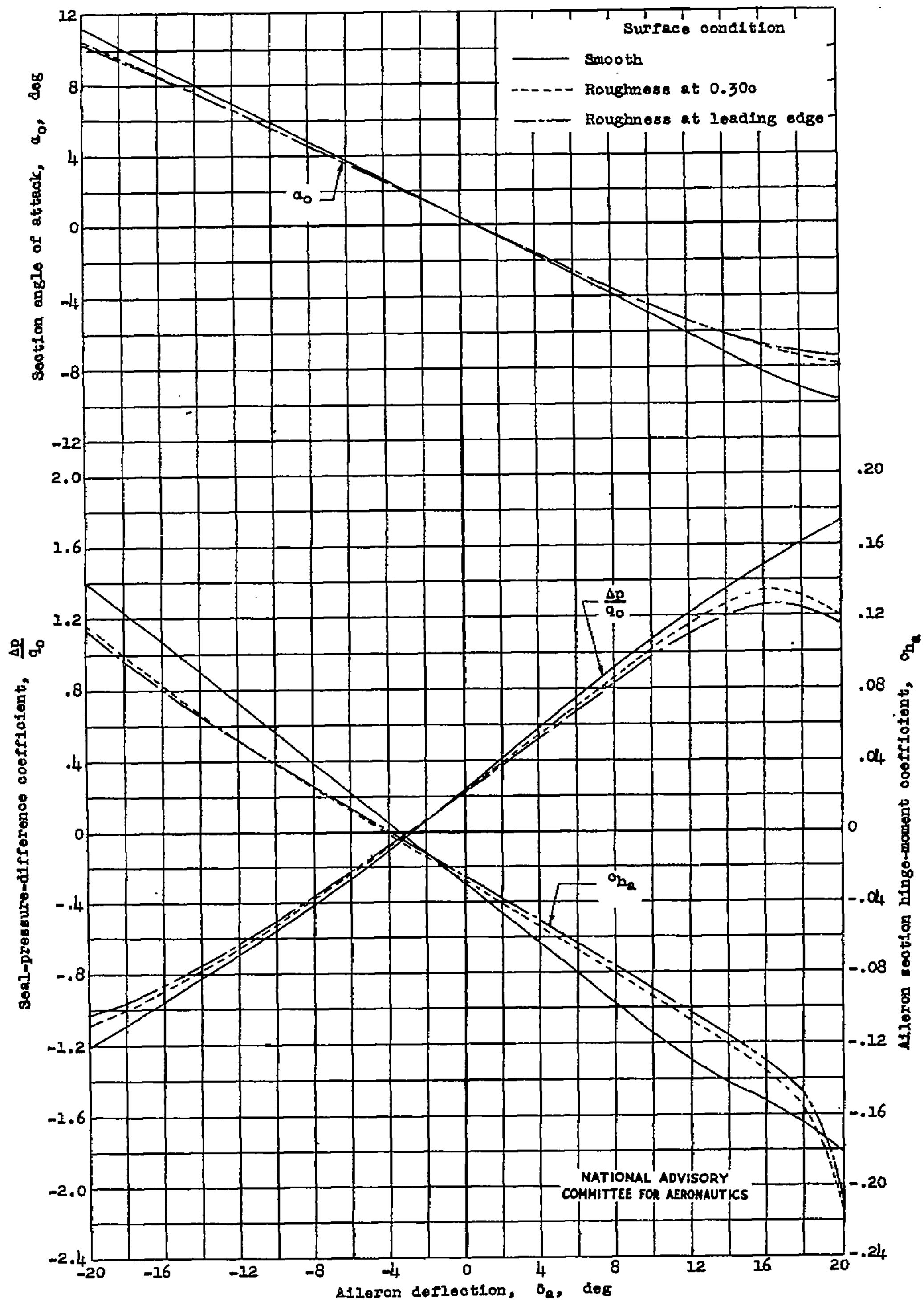


Figure 7.- Variation of section characteristics at a constant section lift coefficient of 0.15 with aileron deflection for the low-drag airfoil section with a 0.24c sealed aileron. $R = 14 \times 10^6$.

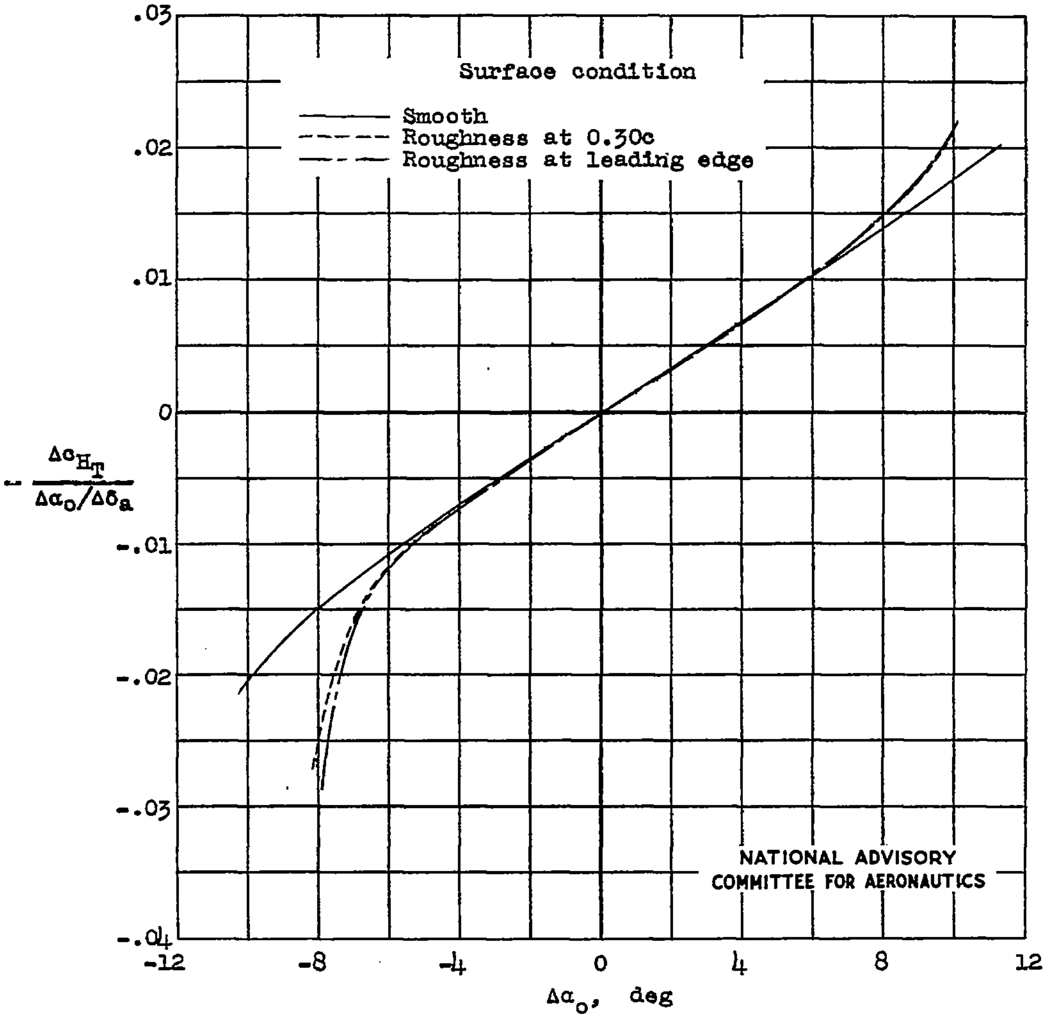


Figure 8.- Variation of the hinge-moment parameter $-\frac{\Delta c_{H_T}}{\Delta\alpha_o/\Delta\delta_a}$ with equivalent change in section angle of attack required to maintain a constant section lift coefficient of 0.15 for deflection of the 0.24c sealed aileron on the low-drag airfoil section. $R = 14 \times 10^6$.

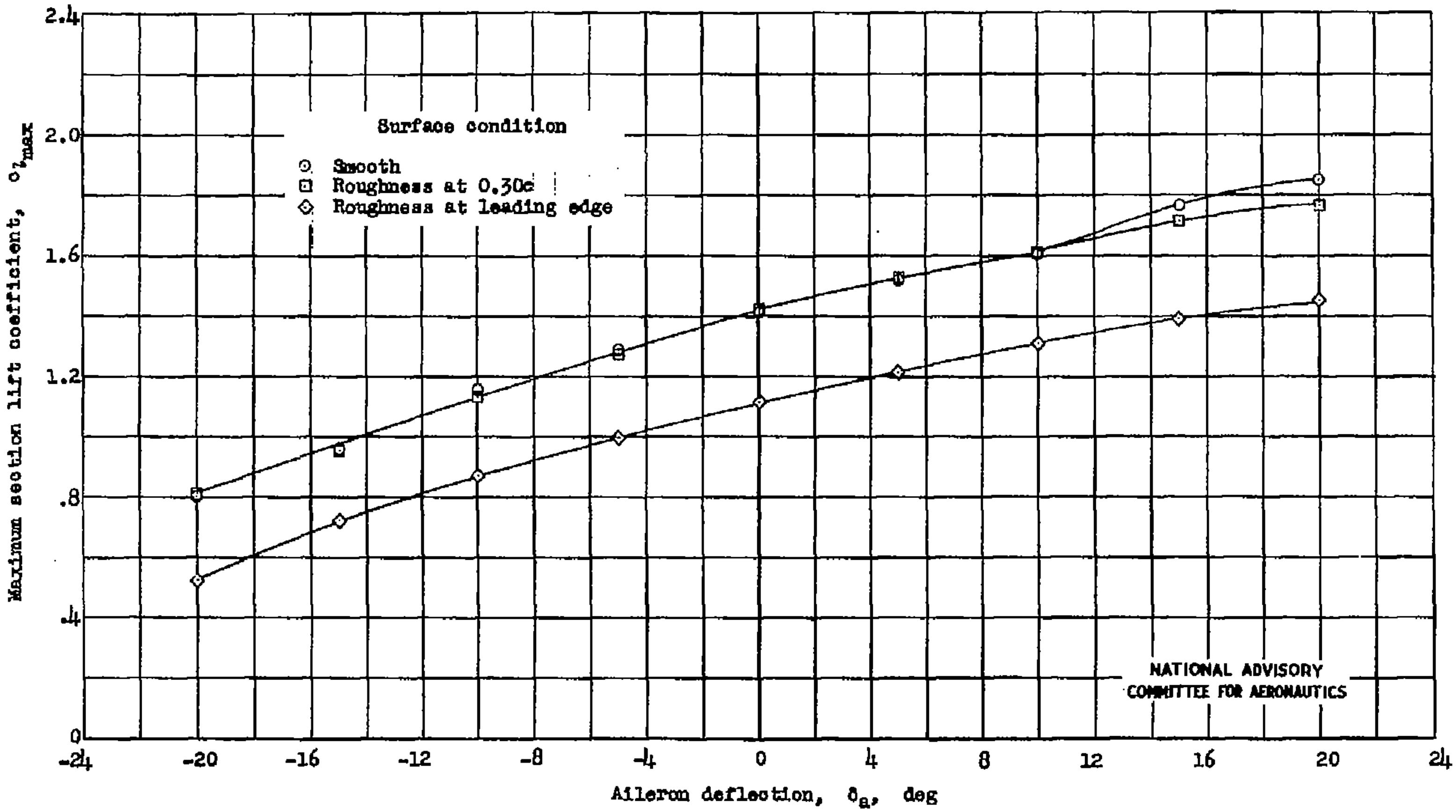


Figure 9.- Variation of maximum section lift coefficient with aileron deflection for the low-drag airfoil with a 0.24c sealed aileron. $R = 14 \times 10^6$.